AD-A093 207 YALE UNIV NEW HAVEN CT DEPT OF PSYCHOLOGY F/G 5/10

REASONING WITH DETERMINATE AND INDETERMINATE LINEAR SYLLOGISMS.(U)

OCT 80 R J STERNBERG N00014-78-C-0025

UNCLASSIFIED RR-9-80 NL

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Reasoning with Determinate and Indeterminate Linear Syllogisms

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Technical Report No. 30
October, 1980

This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N0001478C0025, Contract Authority Identification Number NR 150-412.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report No. 30	2. GOVT ACCESSION NO.: AD-A093 207 — 3. RECIPIENT'S CATALOG NUMBER: (9) Research rept.
4. TITLE (and Subtitle): (6) Reasoning with Determinate and Indeterminate Linear Syllogisms	5. TYPE OF REPORT & PERIOD COVERED: Periodic Technical Report 1 Jul 80 — 30 Sep 80
	6. PERFORMING ORG. REPORT NUMBER: Research Report No. 9-80
7. AUTHOR(s): (10) Robert J. Sternberg	8. CONTRACT OR GRANT NUMBER(s): N0001478C0025
(14) RR-9-80, TR-30	
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Psychology, Yale University, New Haven, Connecticut 06520	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61153N; RR 042-04; RR 042-01; NR 150-412
11. CONTROLLING OFFICE NAME AND ADDRESS: Personnel and Training Research Programs, Office of Naval Research (Code 458), Arlington, Virginia 22217	12. REPORT DATE: (11) 1 Oct 80 (12) 52
	13. NUMBER OF PAGES: 33
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (16) RR04204	15. SECURITY CLASS. (of this report): Unclassified
(17) RR0420401	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

(15) N00014-78-C-0025

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

British Journal of Psychology, in press.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Linear syllogisms, transitive inference, mixture model, deduction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The experiment reported in this article tests a proposed model of linear syllogistic reasoning on both determinate and indeterminate linear syllogisms. The proposed model, which includes processes acting both upon linguistic and spatial representations for information, is shown to be able to account for solution latencies from both kinds of linear-syllogism problems. These demonstrations of the internal validity of the model are accompanied by a demonstration of the external validity of the model whereby composite and c[illegible]

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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scores for individual subjects are correlated with scores from verbal, spatial, and abstract reasoning tests. A number of significant and substantial correlations confirm the relationships of components of the proposed mixture model to performance on tasks quite different in surface structure from the linear syllogisms. It is concluded that although the proposed model is not the true one (in that it does not account for all of the reliable variance in the latency data), it provides a good approximation to the strategy many subjects use in the solution of linear syllogisms.

Reasoning with Determinate and Indeterminate

Linear Syllogisms

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Running head: Linear Syllogisms

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Abstract

The present article tests a proposed model of linear syllogistic reasoning on both determinate and indeterminate linear syllogisms. The proposed model, which includes processes acting upon both linguistic and spatial representations for information, is shown to be able to account for solution latencies from both kinds of linear-syllogism problems. These demonstrations of the internal validity of the model are accompanied by a demonstration of its external validity whereby composite and component scores for individual subjects are correlated with scores from verbal, spatial, and abstract reasoning tests. A number of significant and substantial correlations confirm the relationships of components of the proposed mixture model to performance on tasks quite different in surface structure from the linear syllogisms. It is concluded that although the proposed model is not the true one (in that it does not account for all of the reliable variance in the latency data), it provides a good approximation to the strategy many subjects use in the solution of linear-syllogism problems.

Reasoning with Determinate and Indeterminate Linear Syllogisms

In a linear syllogism, an individual is presented with two premises, each describing a relation between two terms. One of the terms overlaps between premises. The individual's task is to use this overlap to infer the relations among the three terms of the linear syllogism, and then to answer a question that requires knowledge about one or more of these relations. A typical linear syllogism is

Len is taller than Bob.

Bob is taller than Sam.

Who is tallest?

Linear syllogisms such as this one are referred to as <u>determinate</u> because it is possible to determine from the premises the (height) relation between each possible pair of terms. In this particular problem, an individual can infer that Len is tallest, Sam is shortest, and Bob is intermediate in height between Len and Sam. The answer to the question is therefore "Len." Had the question been "Who is shortest?" it would have been answerable as well, and the answer would have been "Sam."

Not all linear syllogisms are determinate. Consider the linear syllogism

Len is taller than Bob.

Len is taller than Sam.

Who is tallest?

In this problem, the correct answer is again "Len." But note that if the question had been "Who is shortest?" it would have been unanswerable, because the premises do not contain sufficient information to infer the answer. Although one knows that Len is tallest, one cannot distinguish between the relative heights of Bob and Sam.

Linear syllogisms such as this one, which do not permit inference of the (height) relation between each possible pair of terms, are referred to as indeterminate.

Psychologists have been investigating the representations and processes people use in solving linear syllogisms since Burt's (1919) adoption of the linear syllogism for one of his tests of mental ability. In recent years, a vigorous debate has arisen regarding whether subjects' representations of the relations among terms are spatial (DeSoto, London, & Handel, 1965; Huttenlocher, 1968; Huttenlocher & Higgins, 1971), linguistic (Clark, 1969a, 1969b), spatial earlier during practice with the items and linguistic later during practice (Johnson-Laird, 1972; Wood, Shotter, & Godden, 1974), linguistic earlier during practice and spatial later during practice (Shaver, Pierson, & Lang, 1974), or both spatial and linguistic (during all phases of practice) (Sternberg, 1980a, 1980b, 1980c). Others have claimed that representation can be of limited import: Quinton and Fellows (1975) have suggested that at least some subjects use a shortcut algorithm that all but bypasses the need for complex reasoning on any kind of data base. Although the nub of the debate has been the form of representation individuals use in solving linear syllogisms, the debate has also concerned the processes individuals use: Investigators proposing different representations of information have also proposed different processes to operate upon these representations.

The debate regarding representation and process in linear syllogistic reasoning has proceeded on the basis of an incomplete data base, because with the exception of Clark (1969a), no one has investigated in detail performance on indeterminate linear syllogisms. Yet, there is no reason to believe that indeterminate problems are of any less consequence than determinate ones. The transitive inferences one needs to make in everyday life often need to be made on the basis of partial and necessarily incomplete information regarding the complete set of items that might be of interest. For most people, making decisions on the basis of partial informa-

tion is a way of life. Moreover, there is no a priori reason to believe that the representations and processes used in solving determinate linear syllogisms (or problems of other kinds) are the same as those used in solving indeterminate ones. Without suitable modification, the models of linear syllogistic reasoning that have provided at least moderately good descriptions of data obtained from determinate linear syllogisms would provide only poor descriptions of data obtained from indeterminate ones.

This experiment does not seek to compare alternative information-processing models of linear syllogistic reasoning. Such comparisons have been carried out in a set of experiments investigating subjects' performance in solving determinate linear syllogisms (Sternberg, 1980a, 1980b, 1980c), and all of the experiments have supported the mixture model over the competing spatial, linguistic, and algorithmic models. In the present context of indeterminate as well as determinate linear syllogisms, only Clark (1969a) has extended his linguistic model to apply to indeterminate linear syllogisms. In the form it is presented, Clark's extended model does not permit quantification; the model can be quantified with a few reasonable assumptions, however. When these assumptions are made, the quantitative predictions of the model for indeterminate problems are the same as those for the mixture model. Hence, the present experimental context was not a suitable one for testing of alternative models. It was suitable, instead, for extending the information-processing stipulations and quantitative predictions of the mixture model to incorporate indeterminate as well as determinate linear syllogisms.

The goal of the present experiment, then, is to extend our understanding of how people solve linear syllogisms to indeterminate as well as determinate reasoning problems. In an effort to reach this goal, an information-processing model is proposed and then internally validated on latency data collected from college students asked to solve both determinate and indeterminate linear syllogisms. The model is

externally validated by correlating composite and component scores with scores on psychometric ability tests. The overall validation procedure is intended to show both the ability of the model to account for the present experimental data and the relation of model parameters to external measures.

Model of Linear Syllogistic Reasoning

This section describes the proposed model of linear syllogistic reasoning. The mixed model has not been previously extended to indeterminate items, but is so extended here. The information-processing and mathematical models described here are extensions of the models proposed by Sternberg (1980c). The model will first be described in its application to determinate problems, using as an example, "C is not as tall as B; A is not as short as B; who is shortest?" The extension of the model to indeterminate problems, using as an example, "A is taller than B; C is shorter than A; who is shortest?" will then be described. A flow chart for the model is presented in Figure 1.

Insert Figure 1 about here

According to one mixture model (of the many that are possible), information from the two premises of a linear syllogism is first decoded into a linguistic format and then recoded into a spatial format. When the subject is asked who is tallest, the subject scans the spatial array for the correct answer, and in certain cases, confirms the result of this scan by checking the linguistic propositions. This model attempts to capture some of the best features of the spatial and linguistic models, and also contains features found in neither of the previous two models.

The terms of the syllogism are first decoded from surface-structural strings into linguistic deep structures. These linguistic deep structures then form the basis for the construction of spatial arrays, one for each premise. Marked adjectives are

assumed to increase processing time, both through increased linguistic decoding time and through increased spatial encoding time. Negations are handled with new arrays constructed from the original arrays by flipping the elements of the original arrays in space.

Consider first how information is combined in determinate problems. In order for the subject to combine the terms of the premises into a single spatial array, the subject needs the pivot (middle term) available. The pivot is either immediately available from the spatial encoding of the premises, or else it must be located. The pivot is immediately available in all (a) affirmative problems and (b) negative problems in which the second premise begins with the pivot. Pivot search is assumed to be needed if the working-memory demands of the problem exceed working memory capacity (see Sternberg, 1980c). In the example problem, the second negative premise does not begin with the pivot, but with an end term, so that the pivot must be located as the term that overlaps between the two two-item spatial arrays. Once the pivot has been located, the subject seriates the terms from the two two-item spatial arrays into a single three-item array. In forming this spatial array, the subject starts with the terms of the first premise, and ends with those of the second premise. The subject's mental location after seriation, therefore, is in that half of the array described by the second premise (which is the top half in the example). The subject next reads the question. If there is a marked adjective in the question, the subject will take longer to decode the adjective linguistically, and to seek the response to the problem at the nonpreferred (usually bottom) end of the array. The response may or may not be immediately available. If the correct answer is in the half of the array where the subject just completed seriation (his or her active location in the array), then the response will be immediately available. If the question requires an answer from the other half of the array, however, the subject will have to search for the response, mentally traversing the array from one half to the

other and thereby consuming additional time. In the example, the subject ends up in the top half of the array, but is asked a question about the bottom half of the array ("Who is shortest?"), requiring a search for the response.

Under certain circumstances, the subject checks the linguistic form of the proposed response against the form of the adjective in the question. In particular, this checking occurs if the terms of the premises have not been carefully encoded into a sharp spatial image. If the two forms are congruent, the subject responds with the designated answer. If not, the subject first makes sure that congruence can be established, and then responds (see Sternberg, 1980c). In the example, congruence must be established, since the shortest term, _C_, has previously been decoded in terms of the adjective _tall_. Once congruence has been established, _C_ can be recognized as the correct answer to the example problem. In the context of the present experiment, checking for congruence was assumed not to be needed, since the need to differentiate indeterminate from determinate linear syllogisms was assumed to encourage careful encoding of the premises of each problem.

Indeterminate linear syllogisms are assumed to be easier to solve, on the average, than determinate ones, because in constructing a single three-item array from the two two-item arrays, one needs to construct a determinate relation between only two of the three possible pairs of relations; in contrast, a determinate linear syllogism requires construction of a three-item array showing determinate relations between all three possible pairs. Processing of indeterminate linear syllogisms can be facilitated only if subjects recognize such syllogisms as indeterminate. In this model, recognition is assumed to occur once the individual premises are each linguistically and spatially encoded. These encodings will be needed regardless of whether the problem is determinate or indeterminate. First, the subject is theorized to query him- or herself as to whether the adjectives in the premises are the same _and_ the positions of the repeated terms the same in each premise. If so, the problem is indetermin ; if not, the problem may still be indeterminate. The subject

next queries him- or herself as to whether the adjectives in the premises are different and the positions of the repeated terms different in each premise. If so, the problem is indeterminate; if not, the problem is determinate. If the problem is indeterminate, the positions of the overlapping term in the two spatial arrays representing the two premises are the same, and the two arrays can be essentially superimposed at the pivot point, rather than joined end to end at the pivot point. Superimposition is assumed to be faster than end-to-end joining. Finally, the subject responds.

Method

Subjects

Subjects were 18 undergraduates attending the Yale summer term. All participated for pay of $2.50 per hour.

Materials

Stimuli were two-term series problems and three-term series problems (linear syllogisms) in which the terms were common male and female names. Half of the three-term series problems were determinate (i.e., the ordering of all three terms along the dimension specified by the problem could be completely ascertained) and half of the three-term series problems were indeterminate (i.e., the ordering of the three terms could not be completely ascertained).

The eight types of two-term series problems varied dichotomously along three dimensions: (a) whether the premise adjective was marked or unmarked; (b) whether the question adjective was marked or unmarked; (c) whether the premise was affirmative or negative. The two-term series problems were used to estimate an encoding parameter (mean three-term latency minus mean two-term latency) in external analysis.

The thirty-two types of determinate three-term series problems varied dichotomously along five dimensions: (a) whether the first premise adjective was marked

or unmarked; (b) whether the second premise adjective was marked or unmarked; (c) whether the question adjective was marked or unmarked; (d) whether the premises were affirmative or negative; (e) whether the correct answer was in the first or second premise.[1] The thirty-two types of indeterminate three-term series problems varied in the same way as the determinate three-term series problems, except that the variation in (e) was in whether the problem was answerable or not, rather than in where the correct answer was. A problem was answerable if one term could be uniquely selected as the answer to the question. A problem was unanswerable if either of two terms could be selected as the answer to the question. In these cases, subjects were instructed to select the answer, "I," signifying an indeterminate problem.

For problems of all kinds, there were three replications of each item type, one using the adjective pair taller-shorter, one using the adjective pair better-worse, and one using the adjective pair faster-slower.

Apparatus

Problems were presented via a Gerbrands two-field tachistoscope with an attached centisecond clock.

Procedure

Subjects were first shown examples of typical two- and three-term series problems, and were told that their task was to solve items of each of these types. These items, and the practice items given later, used the adjective pair older-younger, which was not used in the actual test items. Instructions to subjects indicated that they should solve the problems as quickly as they could without making errors. Testing was done in two sessions. The first session consisted first of the presentation of 12 practice items, equally divided among two-term series problems, determinate three-term series problems, and indeterminate three-term series problems (randomly intermixed). The practice items were followed by 216 test items,

including 24 two-term series problems, 96 determinate three-term series problems, and 96 indeterminate three-term series problems. Items were blocked by the particular adjective pair (taller-shorter, better-worse, faster-slower), with order of blocks counter-balanced across subjects. Determinate and indeterminate items were randomly intermixed. The second session consisted exclusively of ability testing. Subjects received two verbal ability tests--analogies from the Concept Mastery Test and from the Differential Aptitude Test Verbal Reasoning subtest--two spatial ability tests--mental rotation from the SRA Primary Mental Abilities (adult level) and spatial visualization from the Differential Aptitude Test Spatial subtest--and two abstract reasoning ability tests--abstract reasoning from the Differential Aptitude Test (which requires geometric series completions) and figural analogies from the American Council on Education college ability battery.

Results

Basic Statistics

Mean response times were 3.71 seconds for two-term series problems and 8.42 seconds for three-term series problems. Error rates for these two types of problems averaged 1% and 5% respectively. Since the three-term series problems were the problems of primary interest, further analyses dealt almost exclusively with them. The various types of three-term series problems were of unequal difficulty. Mean response times were 8.13 seconds for affirmative determinate problems, 9.64 seconds for negative determinate problems, 7.04 seconds for affirmative indeterminate problems, and 8.89 seconds for negative indeterminate problems. The effect of determinacy was significant, $F(1,17) = 27.00$, $p < .001$, as was the effect of negation, $F(1,17) = 78.36$, $p < .001$. The interaction between the two effects was not significant, $F(1,17) = 3.02$, $p > .05$.

The latency data were highly reliable. Reliabilities (coefficient alpha computed across all possible split halves of subjects) were generally in the high .90s for the entire set of data and for determinate and indeterminate items considered separately.

Mathematical Modeling of Latency Data

Latencies for each of the 32 determinate and 32 indeterminate problems (64 data points in all) were modeled by a linear model based upon the information-processing model described earlier. The complete set of data points is described in Table 1. Table A of the appendix presents the complete set of independent variables and

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Insert Table 1 about here

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values on these variables used to fit the linear models. Psychological referents of the independent variables are described in the presentations of the information-processing model given earlier.

Parameter estimates and model fits (expressed in terms of squared correlations between predicted and observed latencies) are presented in Table 2. Model fits are for all problems, including ones correctly and incorrectly solved. All analyses were also done for problems answered correctly only: Patterns of results were essentially identical to those presented here.

Insert Table 2 about here

The mixture model fared well in predicting the latency data. Further support for the mixture model derives from the fact that all parameter estimates (based on determinate and indeterminate linear syllogisms) differed significantly from zero. The estimates were also plausible. In particular, the value of the response constant (labeled response+ because it also contains within it any other latencies that were constant across item types) seemed at least relatively unconfounded: The value of 4.28 seconds is similar to the values obtained for response in other tachistoscopic tasks such as analogies (see Sternberg, 1977). Model fits were computed separately for each adjective and for each session: Although values of R^2 were generally lower, as would be expected because of the reduced numbers of observations contributing to each data point, the model did about equally well for each subset of data. The good fits of the model to the data and subsets of the data are consistent with the results from seven previous experiments (Sternberg, 1980a, 1980b, 1980c; Sternberg & Weil, 1980). When the same linear model was fit to the data for errors, the squared correlation was equal to .50. Predicted versus observed latencies for the three-term and two-term series problems are shown in Table 1.

The analyses described above have been concerned with internal validation of a model of linear syllogistic reasoning. A separate analysis was done in order to demonstrate the external validity of the task and model. If the linear-syllogism

task is to be of general interest, and if the proposed model of linear-syllogistic reasoning is to be of interest beyond the study of the linear-syllogisms task considered by itself, then it should be possible to show significant relationships between composite and component latencies and scores on tests that have been previously shown to be of interest in predicting a variety of criteria. The verbal, spatial, and abstract reasoning tests used in the present experiment served this purpose. All of these tests have been shown in the past to be useful as predictors of a variety of external criteria, such as grades in school. Because the three kinds of tests were significantlv correlated with each other, both within and between abilities, it was not possible to draw useful conclusions about differential prediction in this experiment. However, the correlations in Table 3 show that composite and component scores on the linear-syllogisms task were significantly and in some cases substantially related to scores on the three kinds of ability tests.

Insert Table 3 about here

Overall latencies were significantly correlated with abstract reasoning ability, and overall error rates were significantly correlated with verbal, spatial, and abstract reasoning abilities. Scores on four of the seven components of interest (excluding the response+ component) were significantly correlated with at least one of the ability scores. The general pattern of results suggest that linear syllogisms provide a useful measure of abstract reasoning ability. The obtained correlations between composite (and some component) scores on the linear-syllogisms task and the abstract reasoning test composite are about as high as different abstract reasoning tests correlate with each other in the psychometric literature. Most of the correlation of the latency score with abstract reasoning seems to derive from the component correlations with abstract reasoning of encoding, marking, and mismatch (see Figure 1).

For the parameters applicable to determinate problems, the patterns of correlations are similar to those obtained in previous analyses (Sternberg, 1980c; Sternberg & Weil, 1980). The indeterminate parameters have not been estimated previously, so no comparison to past data is possible.

Discussion

This study provides the first quantitative test of the ability of any of the primary current models of linear syllogistic reasoning to account for performance on indeterminate linear syllogisms. Mathematical modeling of latency data showed the success of the proposed mixture model in accounting for performance on such items. The mixture model was shown to be externally valid as well as internally valid by correlating component latencies with scores on standardized tests of mental abilities. Several component scores, as well as composite latency and error scores, showed significant correlations with the ability tests.

The present data are consistent with previous data (Sternberg, 1980a, 1980b, 1980c; Sternberg & Weil, 1980) in their support of the mixture model, and further show that the ability of this model to account for solution latencies is not limited to the 50% of the three-term series problems that are fully determinate. In fact, the fit of the model to data was better for indeterminate problems than it was for determinate ones, and it also accounted well for performance on two-term series problems considered either alone or in combination with three-term series problems. The model cannot account for data from three-term series problems with just one negation, but because of the unreliability of data from such problems, neither can any other single model.

The fit of the mixture model to the latency data are well below the reliabilities of those data, and hence the mixture model can be viewed only as an approximation to the still unknown strategy subjects actually use. The model is thus presented as an approximation to the true model, with the hope that future analyses will provide closer successive approximations to what subjects actually do in solving linear syllogisms.

The present data indicate the potential danger of attempting to resolve questions of internal representation in an "either-or" manner. It appears that the irresolubility of the longstanding debate as to whether the internal representation subjects use during the solution of linear syllogisms is linguistic or spatial has derived in part from the fact that both kinds of representations are used at different points during the solution process. If the global data that past investigators have used to compare predictions of spatial and linguistic models have been ambiguous, it is in part because both spatial and linguistic representations are used during solution, and some kind of componential analysis of the data is needed in order to determine which kind of representation is used when.

In componential analyses of the kind presented here, a specter sometimes seems to arise from the possibility that as the range of a given model or set of models is expanded, the number of information-processing components required to account for data from the increasing range of tasks that is analyzed will soon begin to exceed any reasonable bounds. For example, the extension of the mixed model of linear syllogistic reasoning to indeterminate problems required the addition of two new parameters to the model. In this regard, it is worth noting that the processes that are relevant to the current problems are ones that are relevant to many other kinds of problems as well. Negations and marked adjectives, for example, appear in linguistic material of all kinds, and hence the processing of such items is required in almost any kind of text comprehension. As DeSoto et al. (1965) pointed out, people have a notable predilection for linear arrays, and hence the encoding of linear arrays, the search for pivot (overlapping) terms in such arrays, and the search for responses in such arrays, can be expected in a wide variety of tasks, including categorical and conditional syllogistic reasoning as well as linear syllogistic reasoning (see Sternberg, 1980c). As in the present experimental context, arrays can be treated differently, depending upon whether they can be superimposed or

whether they need to be joined end to end. Thus, although the number of proposed information-processing components has increased, the ones identified in this and similar studies seem to be ones that are not specific to a narrow range of information-processing tasks. Instead, we seem to be on the way toward the identification of at least some of those components that matter in intellectual performance.

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Footnote

The research reported in this article was supported by Contract N0001478C0025 from the Office of Naval Research to Robert J. Sternberg. I am grateful to Barbara Conway for valuable assistance in data analysis, and to Pam Costa for typing the manuscript. Requests for reprints should be sent to Robert J. Sternberg, Department of Psychology, Yale University, Box 11A Yale Station, New Haven, Connecticut 06520.

[1] In previous analyses of linear syllogistic reasoning (e.g., Clark, 1969a, 1969b; Sternberg, 1980a, 1980b, 1980c), all problems contained either no negated premises or all negated premises. In the present study, we included problems with one negated premise, but the latency data from such problems were extremely unreliable, suggesting strong intra- or inter-individual differences in strategies for solving such problems. Because of the unreliability of these data, they were excluded from consideration in the present report.

Table 1

Predicted versus Observed Response Times for

Each of the Problem Types

Problem Number	Premises First	Premises Second	Question	Response Times Predicted	Response Times Observed
		Three-Term Series Problems			
		Determinate Problems			
1	A > B	B > C	>	753	721
2	A > B	B > C	<	749	757
3	B > C	A > B	>	703	686
4	B > C	A > B	<	799	808
5	C < B	B < A	>	795	875
6	C < B	B < A	<	891	964
7	B < A	C < B	>	845	953
8	B < A	C < B	<	841	884
9	A > B	C < B	>	799	743
10	A > B	C < B	<	795	727
11	C < B	A > B	>	749	762
12	C < B	A > B	<	845	803
13	B < A	B > C	>	799	813
14	B < A	B > C	<	795	833
15	B > C	B < A	>	749	714
16	B > C	B < A	<	845	961
17	A $\nless$ B	B $\nless$ C	>	997	972
18	A $\nless$ B	B $\nless$ C	<	993	884
19	B $\nless$ C	A $\nless$ B	>	1015	1068
20	B $\nless$ C	A $\nless$ B	<	1111	1167
21	C $\ngtr$ B	B $\ngtr$ A	>	855	880
22	C $\ngtr$ B	B $\ngtr$ A	<	951	944
23	B $\ngtr$ A	C $\ngtr$ B	>	973	921
24	B $\ngtr$ A	C $\ngtr$ B	<	969	1014
25	A $\nless$ B	C $\ngtr$ B	>	1019	[illegible]
26	A $\nless$ B	C $\ngtr$ B	<	1015	[illegible]
27	C $\ngtr$ B	A $\nless$ B	>	969	[illegible]
28	C $\ngtr$ B	A $\nless$ B	<	1065	[illegible]

Table 1 (Contd.)

Problem Number	Premises: First	Premises: Second	Question	Response Times: Predicted	Response Times: Observed
29	B ≯ A	B ≮ C	>	951	918
30	B ≯ A	B ≮ C	<	947	892
31	B ≮ C	B ≯ A	>	901	855
32	B ≮ C	B ≯ A	<	997	958
		Indeterminate Problems			
33	A > B	A > C	>	428	413
34	A > B	A > C	<	474	500
35	A > B	C < A	>	923	794
36	A > B	C < A	<	969	960
37	B < A	A > C	>	923	849
38	B < A	A > C	<	969	1013
39	B < A	C < A	>	520	558
40	B < A	C < A	<	566	522
41	B > C	A > C	>	428	490
42	B > C	A > C	<	474	504
43	B > C	C < A	>	923	862
44	B > C	C < A	<	969	865
45	C < B	A > C	>	923	1002
46	C < B	A > C	<	969	986
47	C < B	C < A	>	520	497
48	C < B	C < A	<	566	441
49	B ≯ A	C ≯ A	>	580	668
50	B ≯ A	C ≯ A	<	626	638
51	B ≯ A	A ≮ C	>	1075	1018
52	B ≯ A	A ≮ C	<	1121	1106
53	A ≮ B	C ≯ A	>	1075	1012
54	A ≮ B	C ≯ A	<	1121	1313
55	A ≮ B	A ≮ C	>	672	671
56	A ≮ B	A ≮ C	<	718	710
57	C ≯ B	C ≯ A	>	580	587
58	C ≯ B	C ≯ A	<	626	577

Table 1 (Contd.)

Problem Number	Premises First	Premises Second	Question	Response Times Predicted	Response Times Observed
59	C $\ngtr$ B	A $\nless$ C	>	1075	1127
60	C $\ngtr$ B	A $\nless$ C	<	1121	1106
61	B $\nless$ C	C $\ngtr$ A	>	1075	1262
62	B $\nless$ C	C $\ngtr$ A	<	1121	1062
63	B $\nless$ C	A $\nless$ C	>	672	704
64	B $\nless$ C	A $\nless$ C	<	718	670
	Two-Term Series Problems				
65	A > B		>	289	283
66	A > B		<	333	339
67	B < A		>	333	365
68	B < A		<	376	314
69	B $\ngtr$ A		>	366	382
70	B $\ngtr$ A		<	409	424
71	A $\nless$ B		>	409	448
72	A $\nless$ B		<	452	411

Note: Response times are expressed in centiseconds. The symbol > refers to the unmarked form of each adjective; < refers to the marked form. The | refers to the negative equative form of the statement. All predictions are for the mixed model.

Table 2

Model Fit and Parameter Estimates

for Three-Term Series Problems

<u>Fit</u>

R^2 (all three- and two-term series problems):	.93
R^2 (all three-term series problems):	.89
R^2 (two-term series problems):	.80
R^2 (determinate problems only):	.80
R^2 (indeterminate problems only):	.93

<u>Parameter Estimates</u>

Marking	46***
Negation	76***
Mixed Pivot Search	68*
Response Search	50*
Construction of Full Determinate Array	275***
Mismatch of Premise Adjectives or Position of Repeated Terms	449***
Response+	428***

Note: All parameter estimates are expressed in centiseconds. Values of R^2 are between predicted and observed latencies.

*$p < .05$

**$p < .01$

***$p < .001$

Table 3

Correlations between Latencies and Reference Ability Test Scores

Latency Measure	Reference Ability Verbal	Spatial	Abstract
Composite Scores			
Overall Three-Term Latency	-.39	-.31	-.58**
Overall Three-Term Error Rate	-.57**	-.48*	-.65**
Component Scores			
Encoding[a]	-.41	-.37	-.57**
Marking	-.37	-.63**	-.70***
Negation	-.01	-.02	-.35
Pivot Search	.04	-.35	-.33
Response Search	-.64*	-.61*	-.27
Construction of Full Determinate Array	-.34	-.23	-.44
Mismatch of Premise Adjectives Or Position of Repeated Term	-.40	-.26	-.61**
Response+	.08	.29	.09

Note: Reference ability scores are means of standard scores of each subject for each of the two tests measuring each ability.

[a]Encoding score used here was estimated as the mean difference in latency between two- and three-term series problems.

*$p < .05$

**$p < .01$

***$p < .001$

Table A

Values of Independent Variables Used to Estimate Parameters

Problem Number	Encoding	Marking	Negation	Pivot Search	Response Search	Seriation	Mismatch
1	2	0	0	0	1	1	0
2	2	1	0	0	0	1	0
3	2	0	0	0	0	1	0
4	2	1	0	0	1	1	0
5	2	2	0	0	0	1	0
6	2	3	0	0	1	1	0
7	2	2	0	0	1	1	0
8	2	3	0	0	0	1	0
9	2	1	0	0	1	1	0
10	2	2	0	0	0	1	0
11	2	1	0	0	0	1	0
12	2	2	0	0	1	1	0
13	2	1	0	0	1	1	0
14	2	2	0	0	0	1	0
15	2	1	0	0	0	1	0
16	2	2	0	0	1	1	0
17	2	2	2	0	1	1	0
18	2	3	2	0	0	1	0
19	2	2	2	1	0	1	0
20	2	3	2	1	1	1	0
21	2	0	2	0	0	1	0
22	2	1	2	0	1	1	0
23	2	0	2	1	1	1	0
24	2	1	2	1	0	1	0
25	2	1	2	1	1	1	0
26	2	2	2	1	0	1	0
27	2	1	2	1	0	1	0
28	2	2	2	1	1	1	0

Table A (Contd.)

Problem..............................Parameter..............................

Number	Encoding	Marking	Negation	Pivot Search	Response Search	Seriation	Mismatch
29	2	1	2	0	1	1	0
30	2	2	2	0	0	1	0
31	2	1	2	0	0	1	0
32	2	2	2	0	1	1	0
33	2	0	0	0	0	0	0
34	2	1	0	0	0	0	0
35	2	1	0	0	0	0	1
36	2	2	0	0	0	0	1
37	2	1	0	0	0	0	1
38	2	2	0	0	0	0	1
39	2	2	0	0	0	0	0
40	2	3	0	0	0	0	0
41	2	0	0	0	0	0	0
42	2	1	0	0	0	0	0
43	2	1	0	0	0	0	1
44	2	2	0	0	0	0	1
45	2	1	0	0	0	0	1
46	2	2	0	0	0	0	1
47	2	2	0	0	0	0	0
48	2	3	0	0	0	0	0
49	2	0	2	0	0	0	0
50	2	1	2	0	0	0	0
51	2	1	2	0	0	0	1
52	2	2	2	0	0	0	1
53	2	1	2	0	0	0	1
54	2	2	2	0	0	0	1
55	2	2	2	0	0	0	0
56	2	3	2	0	0	0	0
57	2	0	2	0	0	0	0
58	2	1	2	0	0	0	0

Table A (Contd.)

Problem Number	Encoding	Marking	Negation	Pivot Search	Response Search	Seriation	Mismatch
59	2	1	2	0	0	0	1
60	2	2	2	0	0	0	1
61	2	1	2	0	0	0	1
62	2	2	2	0	0	0	1
63	2	2	2	0	0	0	0
64	2	3	2	0	0	0	0
65	1	0	0	0	0	0	0
66	1	1	0	0	0	0	0
67	1	1	0	0	0	0	0
68	1	2	0	0	0	0	0
69	1	0	1	0	0	0	0
70	1	1	1	0	0	0	0
71	1	1	1	0	0	0	0
72	1	2	1	0	0	0	0

Parameters were based on the following equalities (See figure 1):

Negation = NEG

Marking = MARK = MARK1 + MARK2 - NMAR1 - NMAR2

Pivot Search = PSM

Response Search = RS

Seriation = SER + SUP

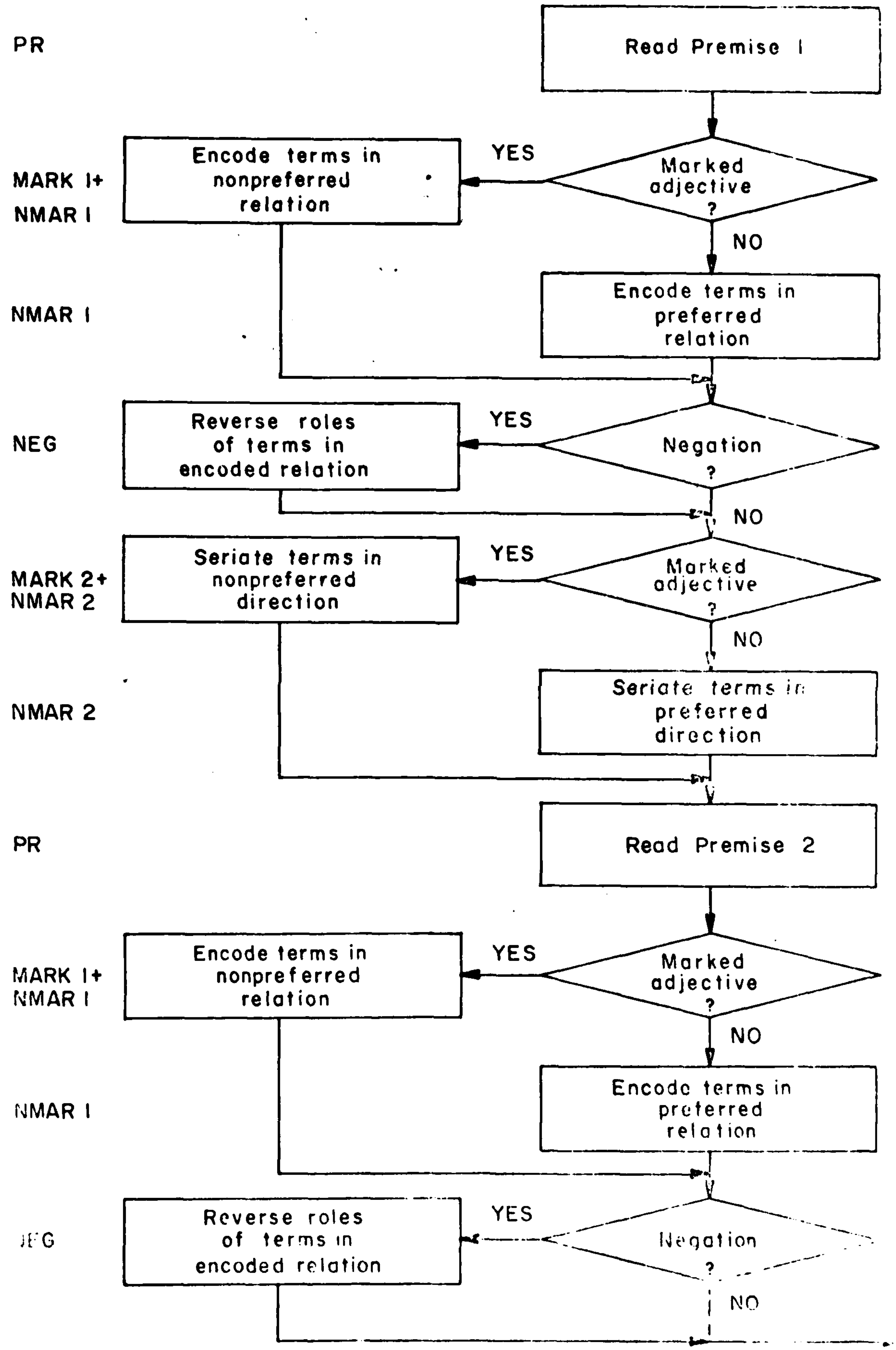
Mismatch = MISM

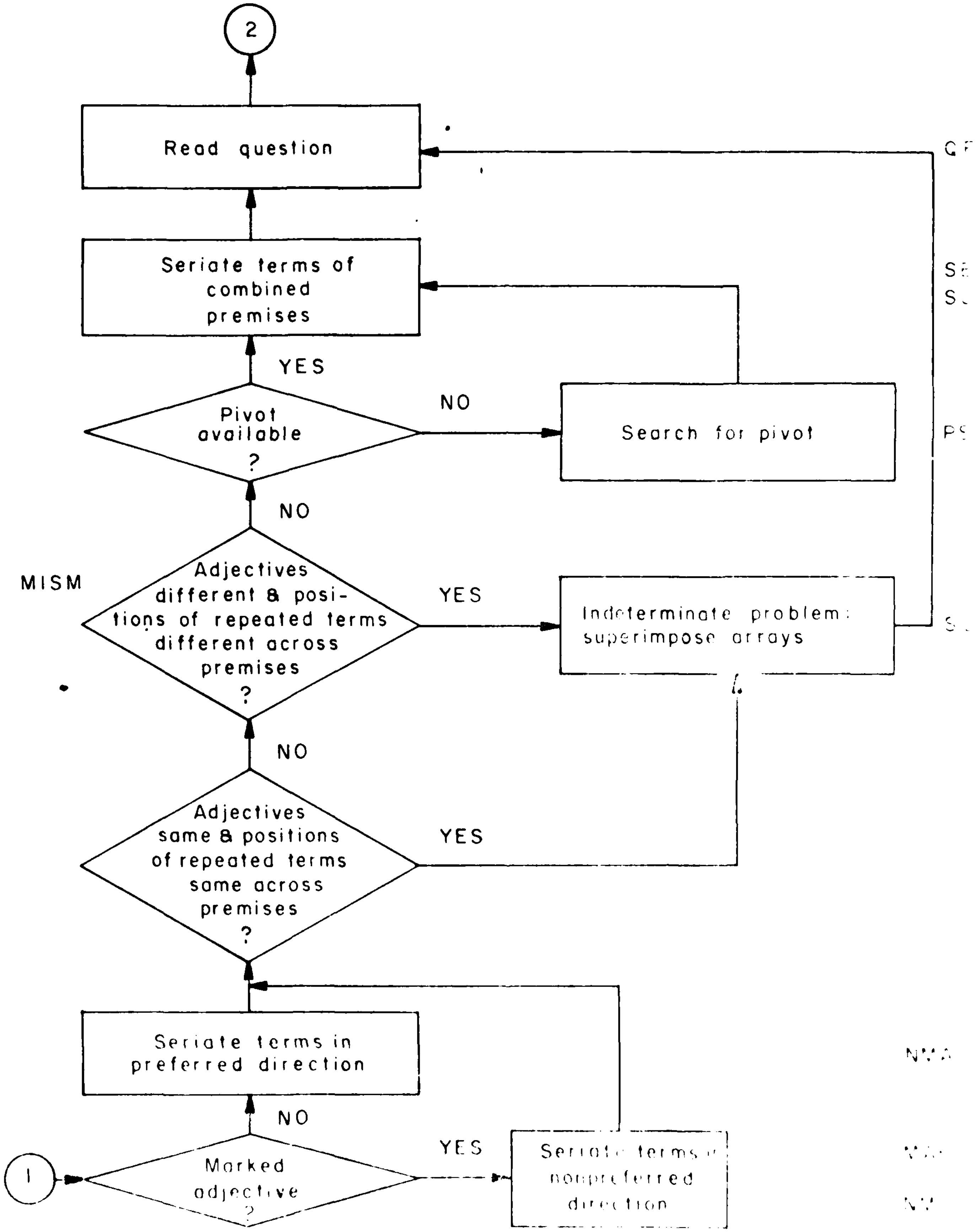
Response+ = RES + OR + (2) PR + (1.5) NMAR1 + (1.5) NMAR2

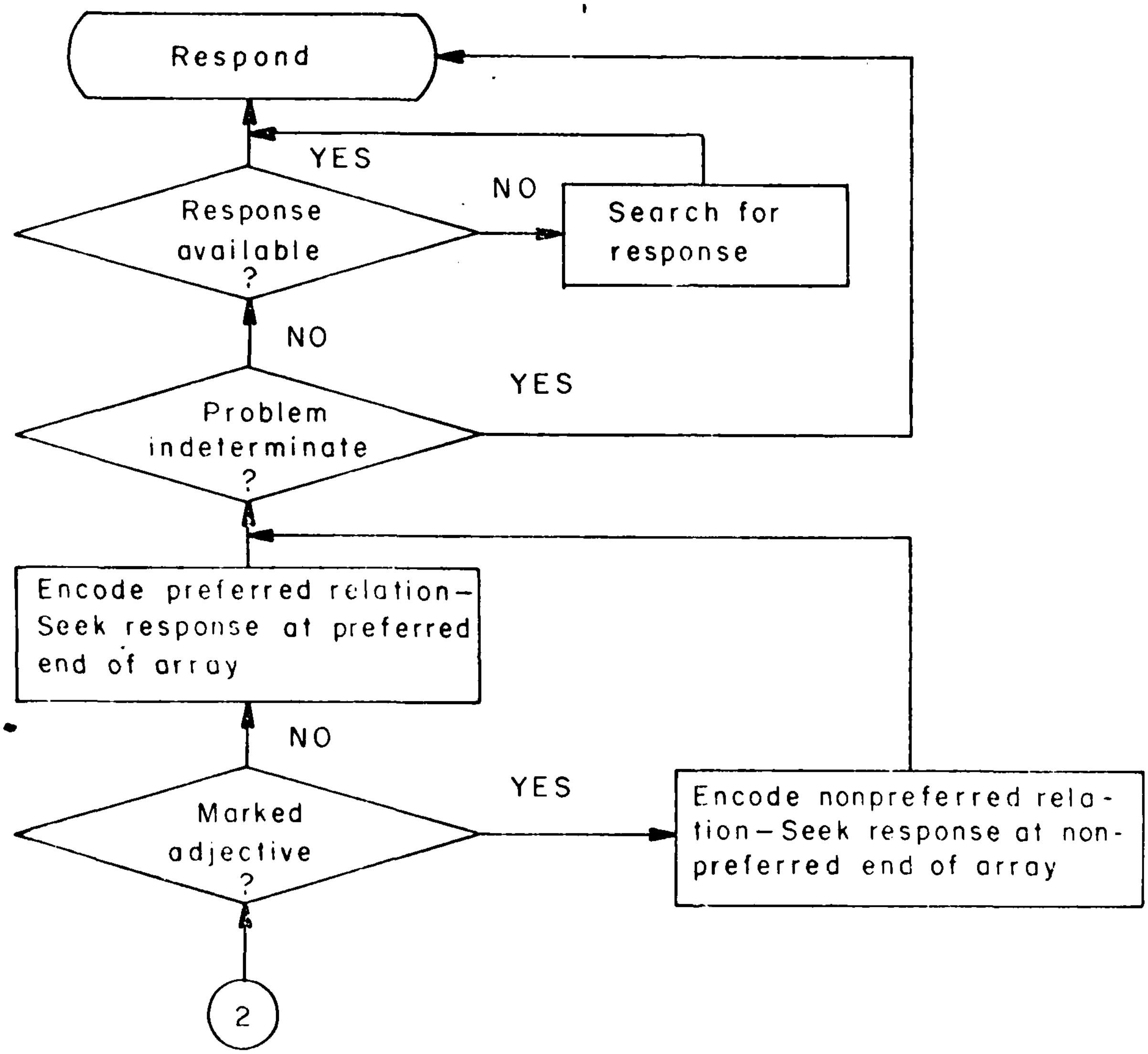
Note: The value of the independent variable for the response+ parameter was always 1. Problem numbers are the same as those in Table 1, where the problems are described.

Figure Caption

Figure 1. Mixed model for determinate and indeterminate linear syllogisms.


PR
Read Premise 1
MARK 1+
NMAR 1
Encode terms in nonpreferred relation
YES
Marked adjective ?
NO
NMAR 1
Encode terms in preferred relation
NEG
Reverse roles of terms in encoded relation
YES
Negation ?
NO
MARK 2+
NMAR 2
Seriate terms in nonpreferred direction
YES
Marked adjective ?
NO
NMAR 2
Seriate terms in preferred direction
PR
Read Premise 2
MARK 1+
NMAR 1
Encode terms in nonpreferred relation
YES
Marked adjective ?
NO
NMAR 1
Encode terms in preferred relation
NEG
Reverse roles of terms in encoded relation
YES
Negation ?
NO


2
Read question
Seriate terms of combined premises
YES
Pivot available ?
NO
Search for pivot
NO
MISM
Adjectives different & positions of repeated terms different across premises ?
YES
Indeterminate problem: superimpose arrays
NO
Adjectives same & positions of repeated terms same across premises ?
YES
Seriate terms in preferred direction
NO
1
Marked adjective ?
YES
Seriate terms in nonpreferred direction



RES

RS

NMAR

+NMAR 2

MAR-

+MAR-

+NMA

+NMAR

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No.	Name	Published Reference
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2	Isolating the Components of Intelligence. January, 1978.	Sternberg, R. J. Isolating the component of intelligence. Intelligence, 1978, 2, 117-128.
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